Tropical Atmosphere Ocean (TAO) Array

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1. PROJECT SUMMARY

FY 2007 funding was expended to maintain the Tropical Atmosphere (TAO) array as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate." TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). TAO/TRITON supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on El Nino/Southern Oscillation (ENSO). Management of the array is consistent with the "Ten Climate Monitoring Principles." Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). Web site containing comprehensive information on the TAO program can be found at (http://www.tao.noaa.gov/). This report summarizes the progress and accomplishments of the TAO project in FY2007. In FY 2007, there were a lot of progress and achievements for the TAO transition from PMEL to NDBC, which are also summarized in this report.

2. FY 2007 PROGRESS

2.1 TAO/Triton Array

2.1.1 Background

FY 2007 was the seventh full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E to 138°W. JAMSTEC added three moorings along 130°E for its own purposes in FY 2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web (http://www.tao.noaa.gov/).

2.1.2 TAO Project Highlights

At present, TAO/TRITON data show atmospheric and oceanic conditions and trends that indicate a weak La Niña exists in the tropical Pacific. Many forecast models that rely heavily on TAO/TRITON data for initialization, suggest that the La Niña will likely continue into early 2008 and may strengthen.

2.1.3 Field work

NDBC is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines, and a nearby subsurface Acoustic Doppler Current Profiler

(ADCP) mooring is deployed. During the past year, NDBC deployed 56 ATLAS moorings and 2 subsurface ADCP current meter moorings in the tropical Pacific. One experimental TAO Refreshed buoy was deployed in the Pacific for a side by side test with TAO Legacy buoys. Four Refreshed TAO buoys were deployed in the Gulf of Mexico as part of development tests.

2.1.4 Ship Time and Sea Time

In FY 2007, 232 days at sea were allocated to the program by NOAA's Marine and Aviation Operations (NMAO) (191 days on *Ka'imimoana* and 41 days on *Ronald H. Brown*) to support the TAO portion of the TAO/TRITON array. This total includes transit days for repositioning the ships and traveling to and from the shipyard. NDBC participated in 629 person-days at sea (number of people times days at sea) and deployed 58 moorings. Due to budget shortfalls at NMAO, *Ka'imimoana's* schedule was cut by approximately 30 sea days in FY2007, reducing the number of buoys serviced for the year. For comparison, during FY 2006, 262 days at sea (220 days on *Ka'imimoana* and 41 on *Ronald H. Brown*) were required to maintain the array, and 71 moorings were deployed.

As part of the TAO Transition, PMEL participated in 261 person-days at sea assisting NDBC with TAO operations and in support of TAO fieldwork.

2.1.5 Data Return

Percentage real-time data return for primary TAO variables integrated over the 55 sites for FY 2007 follows:

	AirT	SST	T(z)	WIND	RH	ALL
FY 2007	90	86	84	77	87	85
FY 2006	91	86	83	82	87	84

All parameters were approximately the same, except the lower wind data during 2007. A primary reason for the lower percentages continues to be the effects of vandalism in the two easternmost lines. Real-time return wind percentages for FY 2007 are 58% and 66%, for lines 95W and 110W, respectively. During FY 2007, twenty-two sites recorded real-time return percentages less than 80% for wind data and thirteen of those reported less than 50% return. The slight increase in the ALL category is due to the increase in the T(z) percentages. The T(z) data account for approximately 80% of the total TAO data.

Eighteen point-source current meters continue to be deployed on the TAO moorings along the equator, near the ADCP moorings. The real-time data return during FY 2007 was 65.8%, an increase of 7.9% from FY 2006. This variable will continue to be reported. PMEL completed a six-year analysis of the point-source current meter performance and has forwarded the results to NDBC and to the manufacturer of the instrument.

2.1.6 Shipboard Measurements

CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the Ka'imimoana and Ron Brown. These data are an integral part of the TAO Project, providing in situ calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

A total of 241 CTD casts were made on TAO cruises in FY 2007, which was a decrease over FY 2006 (58). This large reduction in CTD data resulted from reduction in sea days, equipment problems and several unforeseen problems that required a reduction in CTDs conducted to support ship's needs. The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii.

2.1.7 Guest Investigator Research Projects Using TAO Moorings and TAO Cruises

The primary mission of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of NOAA Ship *Ka'imimoana* is to service buoys of the TAO/TRITON array. However, the TAO Project Office actively promotes use of *Ka'imimoana* and, when it is used for TAO cruises, *Ronald H. Brown* for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time or for a limited number of cruises. An ongoing project is either planned or has been onboard already for several years. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY 2007 (Project, Principal Investigator, Institution (Ship):

- Underway CO2, Richard Feely, NOAA/PMEL (KA and BROWN)
- Turbulent flux measurements and wind profiler, Chris Fairall and Jeff Hare, NOAA/ESRL (BROWN)
- Carbon cycle, Michael Bender, Princeton University (BROWN)
- Discreet Gas Sampler, Michael Bender, Princeton University (KA)
- Dissolved Inorganic Carbon (DIC) Analysis, Andrew Dickson, Scripps Institution of Oceanography (KA)
- Argo float deployments, Greg Johnson, PMEL (KA)
- Global Drifter Program, Rick Lumpkin, NOAA/AOML (KA and BROWN)
- Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)
- CO2 moorings, Chris Sabine, NOAA/PMEL/Francisco Chavez, MABARI (KA)
- Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)
- Haruphone mooring recoveries/deployments, Robert Dziak, NOAA/PMEL (BROWN)

- Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)
- Underway pO2/pN2- Gas Tension device and O2 probe, Craig McNeil, University of Rhode Island (BROWN)
- Equatorial Box Project, Michael Behrenfeld, Oregon State University (KA)
- Microstructure Chipod development, James Moum, Oregon State University (KA)
- Nutrient Samples, Cathy Cosca, PMEL (KA)
- Lagrangian Float, Ren-Chieh Lien, Eric D'Asaro, University of Washington,(KA and BROWN)
- Tsunami/DART, NDBC, Shannon McArthur
- Turbidity/fluorescence CTD measurements, Pete Strutton, Oregon State University (KA)

b. One-time or limited-term ancillary projects on TAO cruises for FY 2007 (Project, Principal Investigator, Institution (Ship):

- Moored Fluorometer deployments, Pete Strutton, Oregon State University (KA)
- Nutrient-poor seawater collection, Calvin Mordy, PMEL (KA)
- Nitrate and O_2 isotope analysis, Patrick Rafter, Scripps Institution of Oceanography (KA)
- Oxygen Concentration and Isotopic Composition in Upper Ocean, Michael Bender, Oregon State University.

2.2 TAO Project Web Pages

During FY07, the official TAO web site maintained by NDBC at http://tao.noaa.gov/ provided easy access to TAO/TRITON data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. The NDBC TAO web site received 3,436,127 hits and delivered 3,095,018 TAO files to the end users. These web statistics represent a significant increase from previous years partly do to NDBC's usage of Webalizer for web stats, while PMEL uses a custom process. The underlying statistical calculations between PMEL and NDBC numbers are different due to the lack of an industry standard in how files are defined for web statistics purposes. However, while the two sets of numbers cannot be compared across organizations, each set of numbers is relevant when comparing to previous numbers produced by the same organization to determine web activity in terms of growth/decline. NDBC also stood up a mirror web site at NWS Headquarters in Silver Spring, MD. This mirror site is globally load balanced and will automatically redirect any traffic destined for the NDBC web farm to the Headquarters web farm when the NDBC network is inaccessible.

2.3 Operational Use of TAO/TRITON Data

TAO/TRITON data are distributed via the Global Telecommunications System (GTS) to national and international operational forecast centers, such as NOAA's National Centers for Environmental Prediction and the Department of Defense's Fleet Numerical Meteorology and Oceanography Center. Within NOAA, these data are used for operational weather and Pacific tropical cyclone forecasting. The National Core Processing Center for Multi-Channel Sea Surface Temperature (MCSST) uses TAO/TRITON and PIRATA sea surface temperatures distributed via the GTS to perform

validation and improvement to the MCSST processing algorithms. TAO/TRITON and PIRATA are the only moored data used in the MCSST analysis. The Global Temperature-Salinity Profile Program (GT/SPP) collects the TAO/TRITON subsurface temperature and salinity distributed over the GTS and makes them available in real-time via NOAA's National Oceanographic Data Center web site.

Plots of TAO/TRITON Monthly Mean SST and Winds, Five-Day Zonal Wind, SST, and 20^{o}C Isotherm Depth 2^{o}S to 2^{o}N Average, and Five-Day Zonal Wind, SST, and 20^{o}C Isotherm Depth Anomalies 2^{o}S to 2^{o}N Average are transmitted to NCEP monthly for inclusion in the Climate Diagnostics Bulletin. Additionally, plots and data are transmitted to the Integrated Global Ocean Services System (IGOSS) for the IGOSS Products Bulletin. The plots include zonal and meridional average and anomaly winds and average SST and SST anomalies and data made available include SST and SST anomaly and mean zonal and meridional wind and anomalies in netCDF format.

2.4 Vandalism

Vandalism continues to plague portions of the TAO/TRITON arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western equatorial Pacific. In addition to partial mooring hardware and instrumentation losses, 9 complete moorings systems were confirmed lost in the Pacific due to the effects of vandalism and 6 other mooring were missing towers. Two mooring remain adrift in the array and may be lost, but not yet confirmed.

Efforts to combat vandalism continue, though it is not clear they are making much impact. Additional vandalism is expected as Ecuadorian fishing fleet expands its range into the Central Pacific

2.5 Public Service

NDBC participated in Data Buoy Cooperation Panel (DBCP) meetings. NDBC represents the North Pacific Data Buoy Advisory Panel, which is interested in data buoys located in the North Pacific Ocean, and is comprised of members from Canada, China, Japan, Korea, Mexico, and the United States. NDBC also participated in the 6th meeting of the North Pacific Data Buoy Advisory Panel, chaired the Drifter Evaluation Panel, and co-chaired the Science and Technology Workshop.

NDBC attended the NOAA Climate Observation Division 5th Annual System Review Meeting in Silver Spring, Washington DC. The NDBC TAO Project Manager, Dr. Teng, presented a poster paper titled "NOAA's Tropical Atmosphere Ocean (TAO) Buoy Array" at the meeting. Dr. Teng also attended the "Waves and Operational Oceanography 2007 Workshop" and "GLOBWAVE Project Workshop" at the France Research Institute for the Exploitation of the Sea (IFREMER) in Brest, France and discussed PIRATA with their representatives.

NDBC Chief Scientist serves as a US representative to the PIRATA Resources Board, and is actively involved in the PIRATA effort including a working group to identify national contributions to PIRATA. The NDBC Chief Scientist also participated in PIRATA 12 meetings.

NDBC hosted Ms. Hester Viola's during November 2006. Ms. Viola is the Data Buoy Cooperation Panel (DBCP) and Ship Observations Team (SOT) Technical Coordinator. NDBC hosted Ms. Yui Hashimoto of JAMSTEC and NOAA's Office of Climate Observation in March 2007.

NDBC has a standing group of Regional Association Coordinators for the Coastal Ocean Observing System, who provide NDBC updates to the eleven Regional Associations and assimilate suggestions from them for future operations. Landry Bernard, TAO serves as a member of the IOOS Steering Team and was elected as a Marine Technology Society Fellow in 2007. NDBC will serve as the Co-Chair of the Technical Program for the MTS/IEEE(OES) OCEANS 2009 Conference.

With the USCOE Hydrologics Laboratory, NDBC organized and prepared a National Waves Plan and participated in the review and final edits to the document. The NDBC Chief Scientist attended Pirata meetings in Miami, FL in November 2006.

Given the proximity of NDBC's new hurricane buoys to the PIRATA array, NDBC, in consultation with the PIRATA Science Steering Committee, continues to upgrade stations 41040 and 41041 with additional observations to enhance their usage as a climate resource in conjunction with PIRATA. In the second year of this effort, the NDBC Observations Supporting PIRATA (NOSP) project added temperature and salinity profiles and 10m current measurement with a companion mooring near 41041. This adds to the rain and solar radiation efforts of the prior year.

2.6 TAO Transition FY 2007 Accomplishments

In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service instructed the directors of PMEL and NDBC to develop a plan for transferring PMEL operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program Review Team that TAO mooring operations be consolidated with those at NDBC. After several iterations, the Deputy Administrator of NOAA formally approved a TAO transition plan. The TAO Transition is being executed in accordance with the approved TAO Transition Plan of August 31, 2004, and yearly Work Plans.

FY 2007 TAO Transition efforts focused on five areas: (1) NDBC continued the daily/monthly/quarterly QA/QC of TAO real-time and delayed data, (2) NDBC continued as the "Official" TAO web site for QA/QC data, (3) NDBC assumed responsibility for all TAO cruises, (4) development and testing of the TAO refreshed buoy system which is to replace obsolescent components and sensors, and (5) NDBC continued enhancements to a new TAO IT/data system for the refreshed TAO buoy systems (more real-time data via Iridium satellite system).

For the TAO data and IT transition, NDBC accomplished the following goals in FY 2007:

- NDBC took over control of the Service ARGOS account and the management of the release and non-release of TAO data via GTS.
- Established the TAO mirror web site at NWS Headquarters in Silver Spring, MD.
- Migrated the legacy data into the refresh database after an internal parallel testing period.
- Continued to make DAC Management Console enhancements.
- Developed a Draft Data Management Plan
- Updated the TAO IT Detailed Architecture Plan.
- Updated and released the KA ship web page and CTD Cast Data Delivery page.
- Updated the DMAC Operating Procedures Manual for Delayed Mode Data
- Completed the Atlantic PIRATA buoy web page integration into the NDBC TAO and NDBC standard web sites.
- Distributed the Atlantic PIRATA buoy data via GTS using the process that will support the refreshed TAO buoys.
- Established the OPeNDAP services for TAO data distribution.

For the TAO refresh buoy system, NDBC accomplished the following tasks:

- Sensor calibration procedures were developed.
- A shorter, easier to handle payload tube was developed and is being evaluated.
- A Lithium battery pack was developed and is being evaluated.
- A smaller form factor anchor design was developed and is being evaluated.
- An ocean sensor laboratory comparison test was performed between TAO legacy and refresh equipment.
- A flux site configuration of the TAO refresh was developed and is being evaluated.
- A standard TAO configuration was deployed at 2S140W and 9N140W.
- A standard TAO configuration was deployed at 41042 in the PIRATA array.

During FY 2007, NDBC accomplished the following goals for data/IT part of theTAO refresh:

- Continued to enhance the NDBC refreshed TAO database.
- Continued to enhance the TAO real-time processing systems for NDBC AMPS payloads.
- Continued to enhance the NDBC DAC Management Console.
- Continued to enhance the TAO data display and data delivery web pages.
- Supported the use of the DAC management console and Engineering web pages in support of test buoys deployed in the Gulf of Mexico and the Pacific.